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Development of Long-Lifetime, Low-Contamination Beam Dumps for NIF

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ABSTRACT

The laser architecture of the NIF beamlines requires small-area beam dumps to safely absorb back reflections from the output and leakage through the PEPC switch. The problems presented by these beam dumps are that fluences they must absorb are very large, beyond the damage threshold of any material, and ablation of beam dump materials potentially contaminates adjacent optical components. Full scale tests have demonstrated that a stainless steel beam dump will survive fluence levels and energies as high as 820 J/cm² and 2.5 kJ, respectively. Small scale tests with tungsten, tantalum, and stainless steel have demonstrated erosion rates less than about 0.5 $\mu\text{m}/\text{shot}$, with stainless steel having the smallest rate. They also suggest that increased angles of incidence ($\geq 60^\circ$) will greatly reduce the material ablated directly back along the beam path. Keywords: laser beam dump, ablation, optical contamination.

1. INTRODUCTION

The need for beam dumps results from the laser architecture used for each of the beamlines of the National Ignition Facility (NIF). Figure 1 shows a schematic of the NIF system with beam paths (above and below) showing extraneous beams which need to be blocked. For normal operation, a pulse is injected near the pinhole plane of the transport spatial filter (TSF). It passes backwards through the

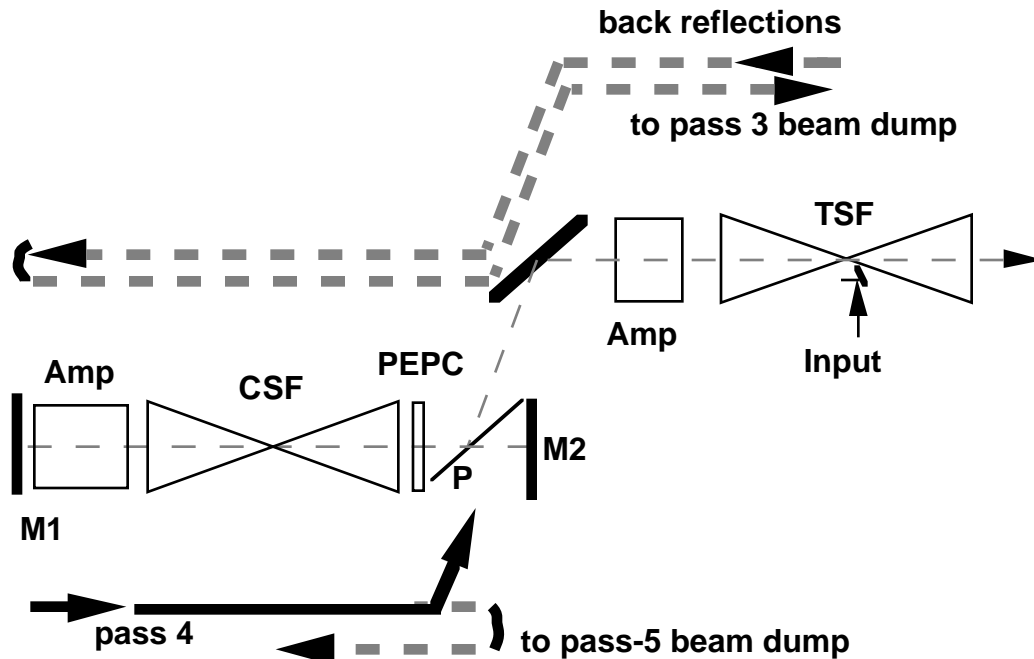


Fig. 1. Schematic of NIF architecture.

booster amplifier, into the 4-pass cavity by reflection from a polarizer (P), and toward the optical switch--a plasma-electrode Pockels cell (PEPC). At this point the PEPC has not yet been energized, and the pulse

passes through with no change. After passing twice through the cavity spatial filter (CSF) and cavity amplifier, the pulse returns to the PEPC, which by this time has been activated. It changes the polarization of the pulse by 90° , and the pulse passes through the polarizer to M2, reflects back through to the energized PEPC and on to the CSF for passes three and four through the cavity amplifier. During these passes, the PEPC is de-energized, so the polarization of the pulse is not changed on its 4th pass through the PEPC, and it reflects from the polarizer, through the booster amplifier and TSF, and on toward the target chamber. In this architecture, the passes are separated by a small angle, ~ 1.2 mrad. Consequently, they are spatially separated near the pinhole planes of the spatial filters, and each pass uses a separate pinhole. There are 4 pinholes in the CSF and 2 in the TSF.

Beam dumps are required because of the possibility of back reflections and because of leakage through the optical switch. Back reflections at 1ω from the target chamber might occur because of stimulated Brillouin scattering or specular glints from shine shields surrounding the target or from the mount holding the target. Misalignment at a spatial filter pinhole can also create back reflections by stimulated Brillouin scattering. Back reflections propagate backwards through the booster amplifier and into the multipass cavity. Although the PEPC remains de-activated, back reflections still make two passes through both the cavity and booster amplifiers, as shown by the heavy dashed line at the top of Fig. 1. A 0.1% back reflection of the chain output can produce as much as 2.5 kJ heading backwards along the direction of pass 3 into the TSF. Since pass 3 does not normally propagate to the TSF, there is no need to maintain clearance for pass 3 in the TSF, and a beam dump can be positioned to absorb the amplified back reflection near the pinhole plane of the TSF, where the passes are spatially separated.

A second beam dump is required to absorb leakage through the optical switch. NIF specifications allow this leakage to be as large as 1%, which could result in as much as 100 J leaking through the polarizer. This leakage would reflect back toward the CSF along the path of a fifth pass, as indicated at the bottom of Fig. 1. Since there is no need to maintain clearance for pass five in the CSF, as with pass three in the TSF, a beam dump can be positioned to absorb this leakage near the pinhole plane of the CSF.

The maximum size of the beam dumps is limited to less than the spacing between pinholes (d), as indicated in Fig. 2. The choice of d is a compromise between the risk of coupling between adjacent passes

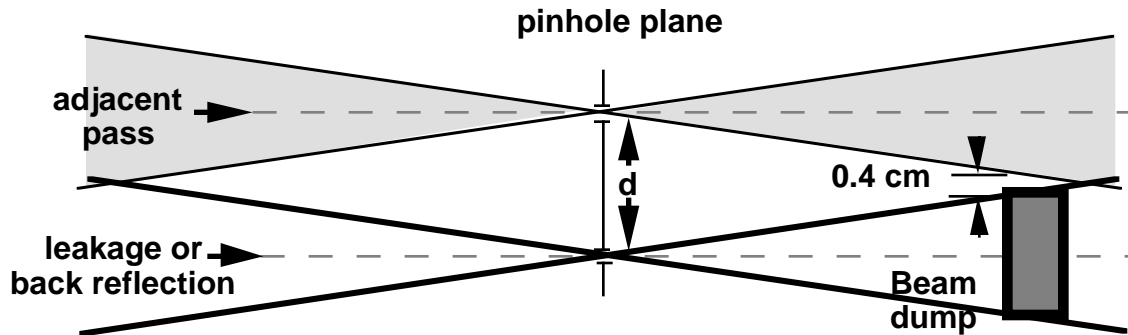


Fig.2. Schematic of spatial filter pinhole area.

(smaller d) and a decrease in beam size and therefore output energy due to increased vignetting (larger d). The spacings selected for the NIF spatial filters are indicated in Table 1. The table also lists the maximum beam area at the dump and the spatially averaged fluence at the dump (both measured normal to the beam direction), assuming a minimum of 0.4 cm between the edges of adjacent passes for mounting and alignment of the beam dumps.

Table 1

Position	$d(\text{cm})$	Max area (cm^2)	Energy (J)	Fluence (J/cm^2)
TSF	3.5	9.6	2500	260
CSF	1.4	1	100	100

The beam dump in the CSF which absorbs leakage through the optical switch will have to absorb some energy on every shot, although most shots will produce less than the worst-case 100 J indicated in Table 1. Since we would like all beam dumps to last the lifetime of the laser, our goal is to have the CSF dump last in excess of 10,000 shots. The current position in the NIF design for the CSF beam dump is consistent with the maximum area in Table 1.

The TSF beam dump which absorbs back reflections should not have to absorb energy on every shot, because back reflections at 1 ω will be accidental occurrences. We are planning for a back-reflection frequency of 10%, which means a required lifetime for the TSF beam dumps of only 1000 shots. However, the current NIF design has the TSF dumps much closer to the pinholes than assumed in Table 1, and the average fluence for the worst-case back reflection will be over 2 kJ/cm². Consequently, the TSF beam dumps are the more difficult problem by far.

The difficulty for both beam dumps is that these worst-case fluences are well over the damage thresholds for any optical materials. Even the best transmissive materials like laser glass and fused silica have damage thresholds less than 50 J/cm². Therefore, any beam dump will "damage", in that the beam will ablate material from the dump and create a plasma at its surface. The problem then becomes how to make the dump survive the required number of shots and how to prevent contamination of other intra-spatial-filter optics from the ablation products.

Beamlet successfully uses high damage threshold absorbing glass for its CSF beam dumps. The absorbing glass is made from laser glass by doping it with Cu to produce absorption at 1 ω . However, the 3 cm pinhole spacing on Beamlet reduces the worst case fluence to about 25 J/cm², which is comparable to the damage threshold of the absorbing glass. The TSF beam dump on Beamlet is also made from this Cu doped laser glass, but it has been damaged by back reflections from the output pinhole and replaced. Although the observed frequency of back reflections on Beamlet is much lower than 10%, Beamlet doesn't run target shots which are the most likely source of back reflections.

2. ABSORBING GLASS VERSUS METAL BEAM DUMP

Initial tests on beam dump materials were done at about 200 J/cm² for a first determination of survivability at fluence levels well above the highest damage thresholds. Absorbing glass and metals have been investigated as the intercepting wall material for the beam dumps. Small scale tests on Cu-doped laser phosphate glass with absorption of 1.8/cm and stainless steel have been conducted at 200 J/cm². Measurements were made of laser back scatter into a 3 mr cone centered on the beam line. This back scatter was determined to be $<2 \times 10^{-6}$ for both materials, which is small enough not to present additional back-reflection problems.

Both materials displayed surface melting and ablation. The ablation products were emitted in a plume normal to the sample, symmetrically distributed about the surface normal. The glass displayed internal fracture after a few shots. The stainless steel showed no significant damage; only the footprint of the beam was visible after 16 shots. These initial tests suggested that stainless steel might be utilized in a low cost, long lifetime beam dump at high fluences.

3. PROTOTYPE METAL DUMP

A recent test series on Beamlet provided an opportunity to test a prototype metal beam dump at NIF-like energy and fluence. The test series required that only the frequency tripled output be used. A wedged focus lens angularly separated the unconverted fundamental and frequency doubled light from the desired third harmonic light. A beam dump fabricated from 35 mil electropolished stainless steel intercepted the unwanted beams at 60° to the normal in a vacuum vessel. Figure 3 shows the layout of this dump. The first wall was spherical to diverge reflected light. The geometry of the rest of the dump was designed to contain as well as possible the ablation products, and to bounce any reflected light down to absorbing glass at the end.

The dump has successfully intercepted 20 shots with no serious damage. The energy ranged from 700 to 2500 J in a 3 nsec square temporal pulse. Average fluences on the dump were 230 to 820 J/cm².

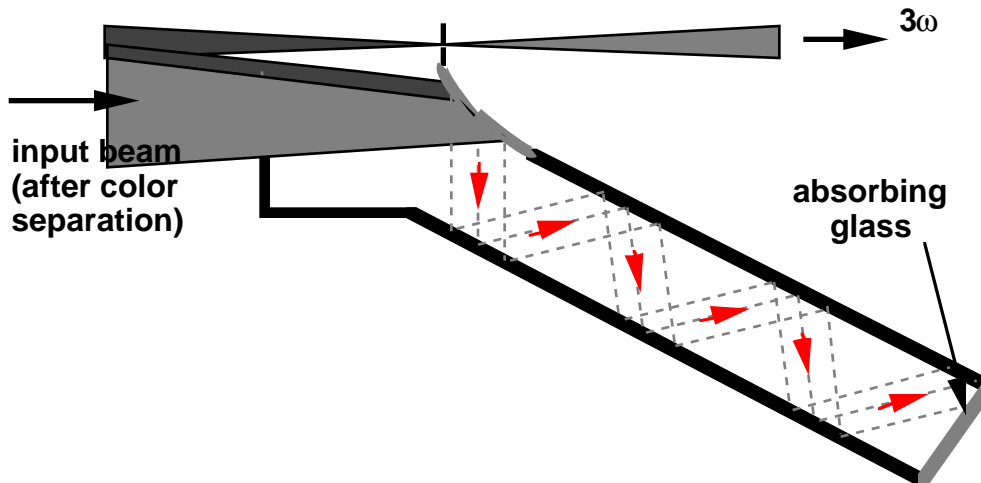


Fig. 3. Schematic of beam dump used in Beamlet tests.

Although the dump survived these shots, it did not function as expected, because the laser energy apparently did not go beyond the first surface. The footprints of both 1ω and 2ω beams can be seen on this surface as shown in Fig.4. The 2ω footprint is substantially less pronounced, because there was relatively

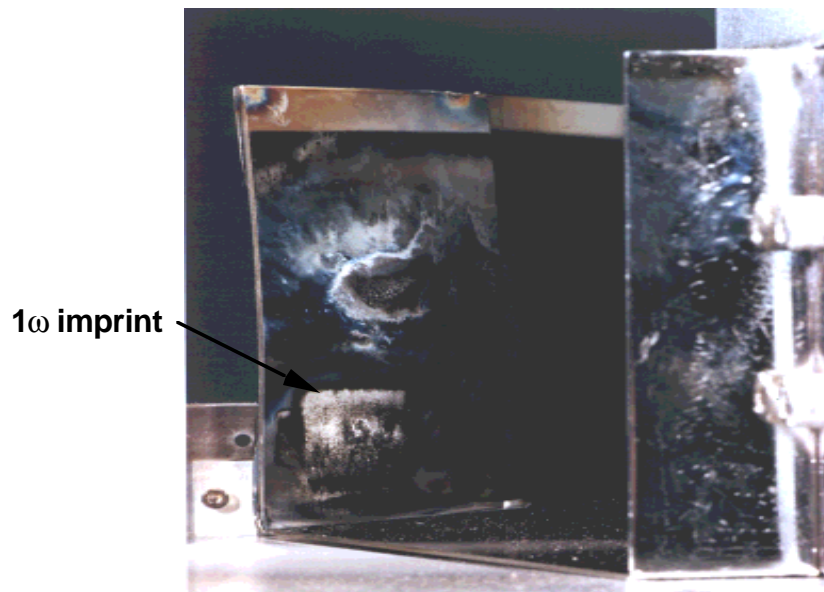


Fig. 4. The first surface of the beamlet beam dump, viewed from the direction of the incoming beam.

little residual 2ω during these tests. The surface directly across from the first surface (i.e., not where a reflection would hit) is heavily scoured, apparently from ablation products. The absorbing glass at the far end of the dump has a very thin deposit, similar to a vacuum coating. The explanation of what occurred to create the markings on the dump walls is not complete.

These tests showed that stainless steel could be used as a beam dump material at NIF-like fluences and survive. Further tests were designed to determine long term survivability and how well the ablation products can be contained.

5 SMALL SCALE TESTS

The layout for small scale tests to look at both long term survivability and ablation product distribution is shown in figure 5. The maximum laser energy used was 16 J in a 16 nsec, full-width-half-

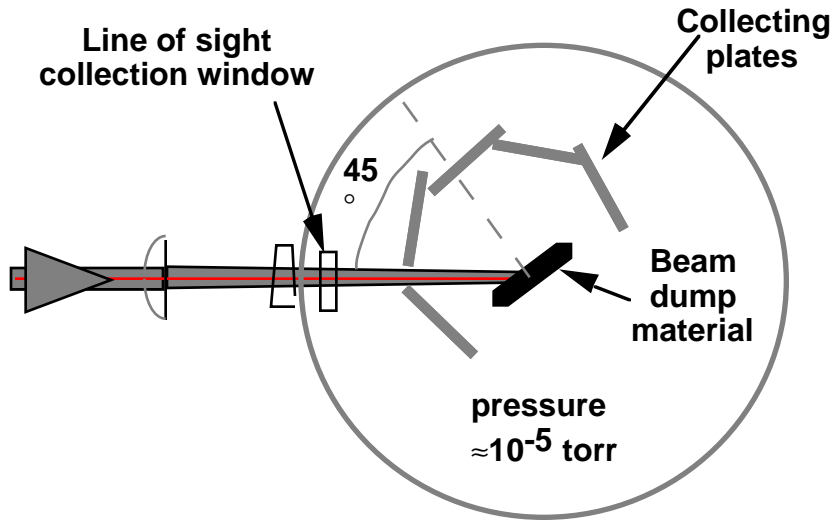


Fig. 5. Schematic of small scale test layout.

maximum pulse, at a maximum repetition rate of 1 Hz, and all tests to date were at 45° as shown in Fig. 5. Typical beam sizes normal to the beam direction at the target were 2 mm square with modulation in the intensity profiles of approximately 1.3:1, peak to average. A 40-cm focal length, F/14 was used to focus the beam, and the sample was placed in the converging beam ahead of focus. Pressure in the vacuum chamber was in the 10^{-5} Torr range. An arrangement of glass microscope slides was used to collect ablation products.

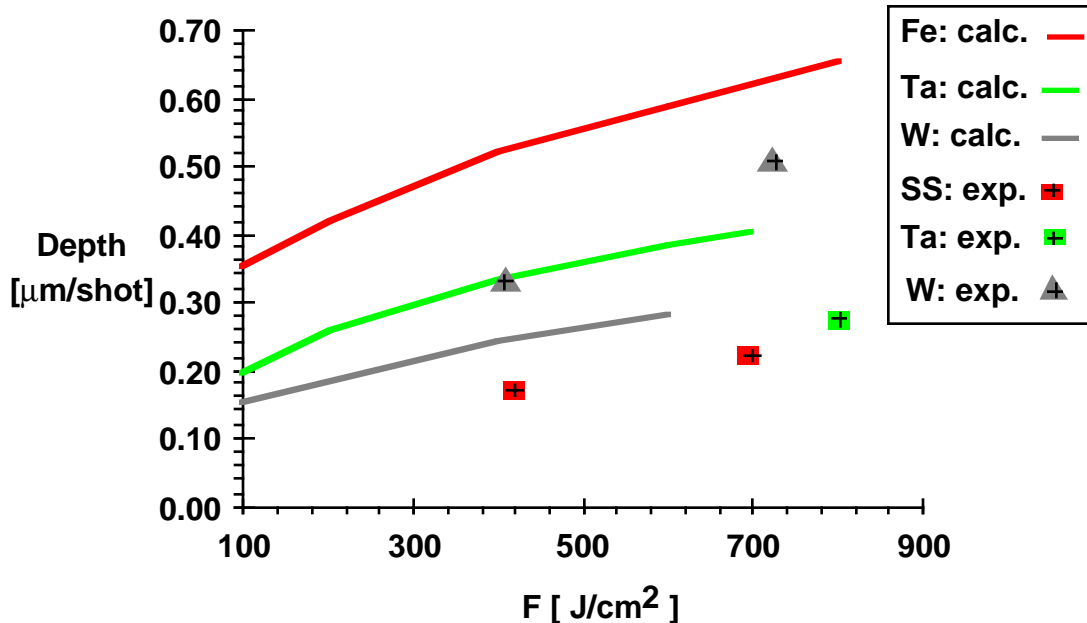


Fig. 6. Experimental and theoretical results for erosion rate.

Tests on 1.5 mm thick samples of stainless steel, tungsten and tantalum showed that all three materials survive 1000 shots at fluences up to 800 J/cm^2 . Figure 6 plots both theoretical calculations (solid lines) and data points (symbols) for the hole depth in microns per laser shot. Erosion rates were

measured with an optical microscope, by measuring the depth from the metal surface untouched by the laser to the flat bottom of the hole left by 1000 shots of the laser. The total depth divided by the number of shots gave the depth of a single shot. Data was collected at laser repetition rates varying from 0.25 Hz to 1 Hz with no significant difference between rates. All three metals show erosion rates of less than $1\text{ }\mu\text{m}$ per shot with stainless losing less than both tantalum and tungsten. Test series with 8 shots and 50 shots gave essentially the same results as a 250 shot series on stainless steel at about 400 J/cm^2 , indicating that erosion rate is independent of shot number on a single site, at least for these conditions.

The calculations employed a 1-D model of heat transport in the material, ablation, and hydrodynamic expansion of the vapor. They show the two higher melting point materials eroding less than the stainless steel. The experimental data show the inverse. The reason for the disagreement is under investigation.

The collection plates were masked horizontally at the beam height so as to provide a step for analysis of the thickness of the deposited material. The first general observation was that the ablation products come off centered about the surface normal. The second was that there was no evidence of particulates on the slides; on the contrary a highly reflecting layer was left on the slides in the thickest regions that adheres extremely well to the slides. A Tencor stylus profilometer was used to determine the thickness of the deposited material. The results for 400 and 800 J/cm^2 on stainless steel are shown in figure 7. The vertical axis shows thickness in nanometers, normalized to a distance between surface and

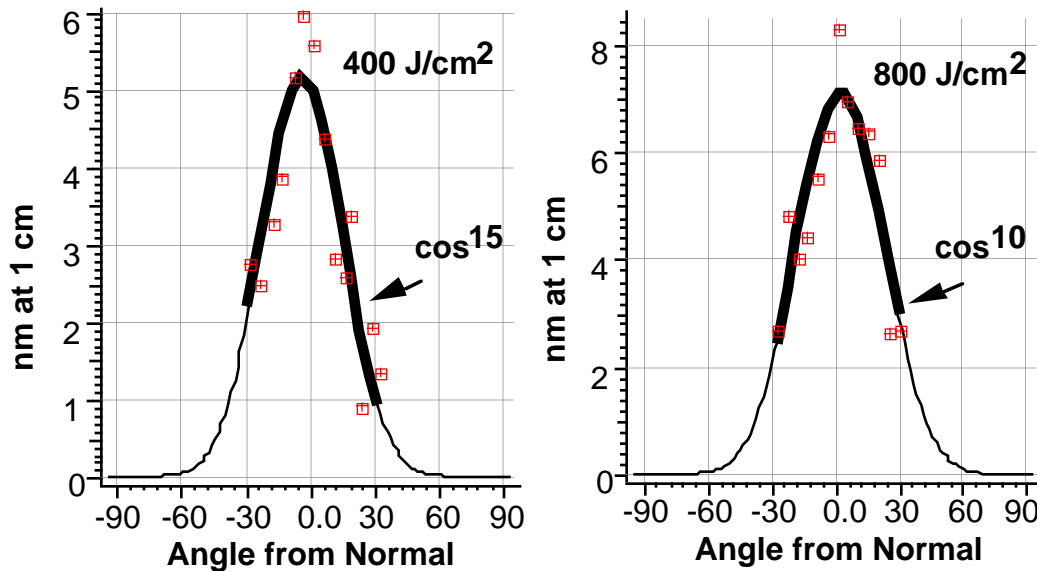


Fig. 7 The angular distribution of ablation products for stainless steel.

collection plate of 1 cm. The profilometer could be used only out to 30° from the surface normal. The line is a fit to the data extrapolated to 90° ; the region of the fit is indicated by the heavy line. The fall-off shows a strong dependence on angle, as strong as \cos^{15} for the lower fluence case. If these dependencies hold to larger angles and for the corresponding larger angles of incidence, operation at large angles of incidence would greatly reduce the material ablated back along the incoming beam direction toward the lens.

5. BEAM DUMP DESIGN CONCEPT

A new beam dump concept has emerged from these results for high fluence locations like those in NIF, as shown in Fig. 8. The dump would be constructed from about 1 mm thick stainless steel in a box-like structure with the beam incident at 60° or more to the surface normal. Side-wall shrouds that completely surround the first wall, except for a pinhole for the incoming beam, would minimize exposure of optics in the spatial filter to ablation products. The pinhole could be as small as the largest pinhole that might be used for the main beam lines.

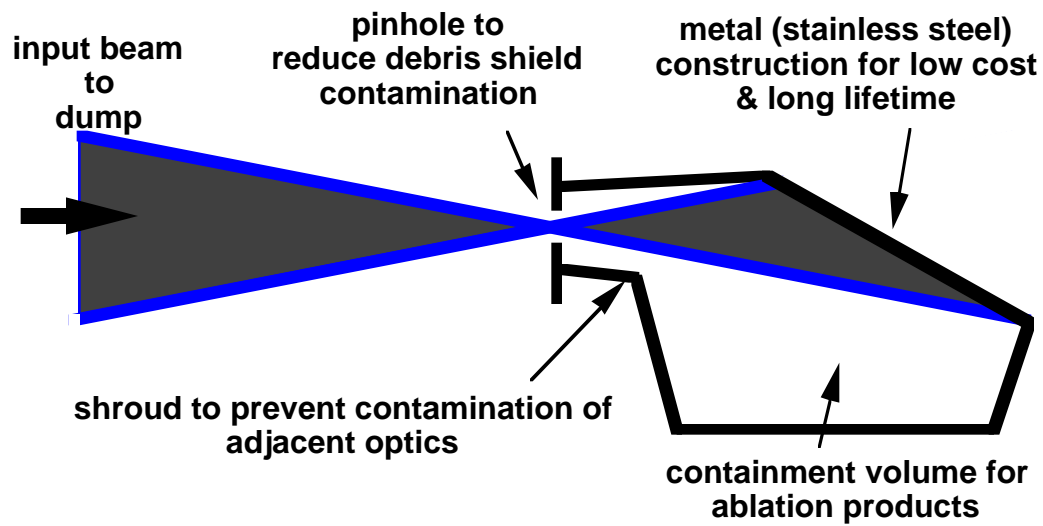


Fig. 8. Schematic of the NIF beam dump.

6. ACKNOWLEDGMENTS

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